Proceedings of 14th IOE Graduate Conference
Peer Reviewed
Year: 2023 Month: December Volume: 14
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Performance Analysis of Technology for Economic Development Model Biogas Plant and Comparison with Modified GGC-2047 Model

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Abstract
TED model biogas plant is a fixed dome type digester. The size of the plant is 20 m^3 having digester volume 12 m^3 and gaseous volume 8 m^3. There has been mixture of feeding. During the study cow manure, human waste and kitchen waste like rice, fruits, vegetables, eggs, pickles, vegetables etc. was fed into the system. The digester was fed with 84 kg mixed waste per day on average generated from the school. The average gases produced per day have been 5425 liters. The plant is able to save nearly 5 cylinder of LPG per month. The recorded burning time for this amount of gas production is 9-11 hours per day in a stove of size 0.25m3. The total solid of inlet feedstock and outlet slurry is 14.58% and 8.13%. The volatile solids of the inlet feedstock and outlet slurry have been 78.59% and 48.98%. Percentage reduction in TS and VS have been 44.24% and 37.71% respectively. The average pH of the outlet is found to 7.1 which is around neutral. It is found to have higher reduction in TS and VS when the kitchen waste and cow manure is co-digested anaerobically. The biogas produced from the plant has been 1.01 m^3/kg of TS and 0.22 m^3/kg of VS. Nitrogen, Potassium and Phosphorus of feedstock has been 0.37%, 0.25%, 1.54% respectively and outlet slurry have been 0.17%, 0.03%, 0.68%. The plant could reduce 12.027 Tonnes of Co_2 equivalent. There have been slightly decreases in the value of the NPK because formation of ammonia gas through formation of ammonium ion. Financial analysis shown that the plants must get subsidized in order to get profitability.

Keywords
Biogas, Technology for Economic Development, GGC-2047

1. Introduction

Energy is a basic need for every human being and plays a vital role in our daily life. Energy helps to create a better world. It has also major role in the economic status of country. There are different sources of energy like fossil fuel, renewable energy and so on. Biogas is one of the clean and affordable type of energy. Generation of biogas from farm waste like animal excrement, wastewater sediment, leftover plant matter, and assorted natural refuse is gaining heightened attention due to its potential to curtail emissions of greenhouse gases (GHGs) and reliance on nonrenewable fuels. It can help to partially replace the current energy demand in a sustainable manner. Global energy consumption scenario shows a high supply from the commercial sources like by the petrol, Diesel, Coal and Natural Gas. As we can see there is gradual decline in use of fossil fuel from 94.55 % in 1970 to 80.04% in 2015; the use of renewable source is around 1.64% in world scenario [1]. Use of biogas skill can reduce the world greenhouse gas emission by 3,290 to 4,360Mt carbon dioxide equivalent. In southern Asia country like India, Nepal and China have large number of domestic bio-digester working around 50 million.

Nepal energy demand is fulfilled by the biomass resources like firewood, coal, cattle cake, agricultural residual and also with hydroelectricity. Nepal electrification rate is increasing day by day, till it hasn't reached to all Nepalese people. Till now 69% of Nepal energy demand is fulfilled by the biomass like firewood, coal and agricultural residual. In Nepal, biogas was introduced in mid-20th century. But it doesn't get the pace it needed to evolve throughout the country. Biogas installation get its pace after the energy crisis of 1975. Nepal in 1975/76 were celebrating that year as agriculture year and along with that the government also started to promote biogas as alternative sources of energy. Agricultural development Bank of Nepal had played a great role in the promotion of biogas by not only disbursing loans to the interested individuals but also by providing training and information dissemination.

In 1977, Gobar gas and Agricultural Equipment Development Company (GGC), a private company, with an objective of promoting biogas technology in the country. After their existence in field of biogas they remained the only organization in the country which helps to promote the biogas technology and also involved in providing training to the individual and also to the masons on its construction process. In 1992, BSPs was initiated to promote biogas in Nepal in the international support of Netherlands Development Organization (SNV). After this initiation, the number of biogas installation started to gradually increase with a good rate. On average there is nearly 20,000 plants installed per year. As per the economic Survey2021/22, the installation of biogas plant in Nepal which is nearly gone past four hundred thousand. The maximum number biogas plants installed between 2014-2016 and least in the 2019/20 fiscal year due to the coronavirus epidemic. And also Figure 2.9 shows the number of institutional, urban and commercial biogas installed. There are only around 345 plants of this type which is very much less in compared to the installation of the domestic biogas plants. As of first eight months of 2021/22 fiscal year, 3,988 biogas plants and 15 institutional, urban and commercial plants are installed. Despite the continuous government's support and financing schemes, less than one percent of the total biogas potential has been harnessed. The total biogas potential of Nepal from livestock is estimated to be 3043.58 million m^3/year when the full potential will be utilized. This estimation could be avoided emissions of 4.35 million tonnes CO2eq/year.

2. Literature Review

Biogas is the one of the cheapest and easily accessible alternative sources of energy for heating, cooking in the rural area and urban also. It also helps to mitigate the dependency on the expensive and harmful energy sources. It is gaining the popularity nowadays due its various good characteristics. The environment of today's world is degraded by the continuous use of non-renewable energy sources like diesel, coal, petrol, natural gases, kerosene, biological materials, solid wastes, trees and etc. These all help to increase the production of the GHGs, this will lead to create a small cover near lower surface of the earth which strengthen the greenhouse effect and contributes to climate change and also, increase the global temperature of the earth. Among various GHGs, CO_2 is the major contributor nearly 79.4% CH_4 is the secondary contributor which emits from the livestock and other agricultural and animal practices, land use and also municipal solid wastes fills. Most of the developed countries like USA, China, India etc. have most percentage of contribution[2]. As per the energy usages scenario nearly 88% of energy demand is met by the non-renewables mostly by fossil fuels. The key benefits of installing small scale biogas plant are clean cooking, cheap cooking and also help to produce fertilizers for growing local vegetables and herbs. Also, it helps to reduce our dependency on natural gases and LPG gases, stove etc. Biogas also help to reduce emission of methane and carbon dioxide and other harmful and GHGs gases.

In the 17th century, Jan Bapista van Helmont, it was determined that decaying organic matter could possibly evolve as a flammable gas. Also, an Italian scientist Alessandro Volta, 1776, found a direct connection between the amount of the decaying organic matter and the produced inflammable gases[3].

By using biogas plant accessible everywhere, the problem for bio-degradable waste can be solved around the plant. Due to the continuous feeding of kitchen waste materials like fruits, leftover foods, fruit, citrus food, vegetables etc. which makes the pH value in acidic region. Due to this the formed methane concentration begins decreasing and which makes difficult to ignite in the stoves. So, to bring down pH to neutral nearabout 7, there must be addition of the cow manure which are basic in nature[4].

Iqbal et. Al. in 2014 observed that co-digestion of CM(Cow manure) and kitchen waste through the AD at temperature of 37°C degraded more rapidly than the kitchen Waste and CM alone. He also observed that when kitchen Waste is treated with alkali (NaOH) at a temperature of 37°C and OLR 200gm/L then the biogas production was almost doubled than untreated kitchen Waste.[5].

Subedi discussed the status of the current situation of biogas in Nepal and its role and contribution to employment, income generation, direct and indirect contribution in reduction of the GHGs gases[6].

Dhungana et al. had looked into single-stage degradation of food waste under room temperature conditions mimicking the functioning parameters of a household biogas facility[7].

Production of biogas, compared to the summer season, is lower during the winter. But the improvement in biogas yield can be done by mixing feedstock with lukewarm water during water. Also, construction of greenhouse is required in order to enhance the biogas production[8].

Kanwar and Guleri compared between the Chinese fixed dome and an Indian plastic tubular digester without greenhouse at an altitude of 1300m and found out that biogas production in the plastic tubular model in winter season dropped by nearly 70% as compared to the production observed in the summer season[9].

Garfi et al. investigated while comparing Chinese fixed dome and plastic tubular digester that plastic tubular digester was easy to install and implement and handle and is also carried out at lower investment than the former[10].

Agyeman & Tao in 2014 suggested that the rate of production of methane and specific methane yield in the digester can be enhanced and increased by using finer size of feedstock. They also suggested that by reducing feedstock particle size digestate dewaterability was improved significantly[11].

Kumar & Samadder, 2020 had discussed that AD is a very much complex microbial process containing of series of metabolic reactions for disintegration of organic matter into major biogas and minor organic fertilizer. In AD, it is found that conversion of biomass to biogas is heavily influenced or enhanced by different types of microorganisms including methane forming bacteria and acid-forming bacteria. The whole AD process is generally divided into four different stages [12].

Christensson et al., 2010 had estimated that biogas mainly consists of methane, carbon dioxide as the main constituents but along there major it also consists of some smaller concentration like nitrogen. Oxygen, hydrogen, hydrogen sulphide [13].

3. Methodology

In this chapter, the methodology that is applied for the work from the start of the project till the completion of the project. The theoretical background and previous use of method and technologies are also elaborated. A brief discussion of financial analysis is also presented in this chapter. The methodology used during the study is shown in figure 1.

Materials and methods Data collection is one of the most important aspect of any research which helps to determine the quality and output of any research. The study was performed by taking the useful and relevant data from the biogas plant of Bloom Nepal School situated in Mahalaxmi municipality, Lalitpur. The latitude and longitude of the plant was 27.633°N, 85.362°E. The general layout of the biogas plant is shown in figure 2.The system was installed in the end of 2021, and the data was taken only after the plant or system is well running

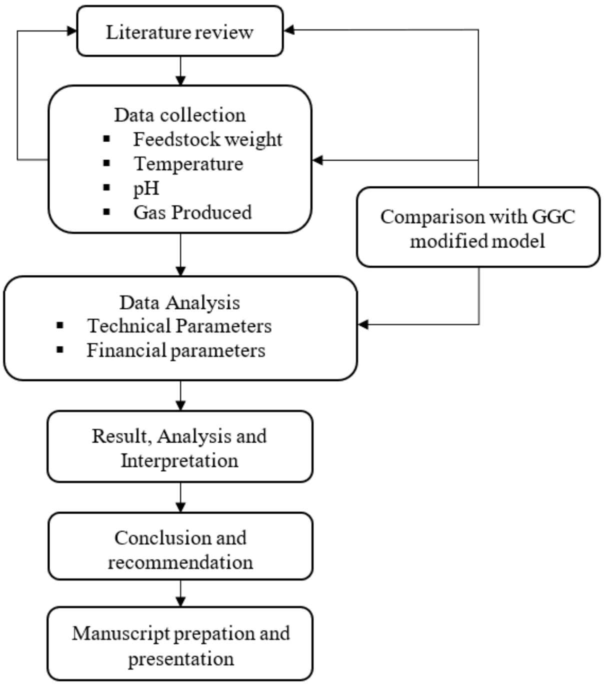

Figure 1: Research Methodology Flowchart

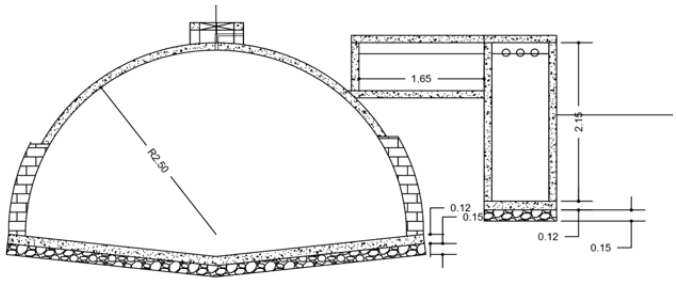

Figure 2: General Layout of TED Model

and better performing condition. The plant was installed on 15th Feb 2022. For the activation of system there need to put 200 kg of cow manure with water. The mixture should be in 2:1 ratio of water and cow manure. Rest part of digester tank has been filling by water until there is flow from the fertilizer outlet. The system was left to stabilize until there has seen gas. Gas has been seen after 12 days of installation and after burning of the gas started, maximum pressure arises after 8 days. A log sheet containing feedstock inlet weight and daily gas consumption to the caretaker of the plant and kitchen worker. The plant has been visited once a week to look out for relevant data like installation cost, operating and maintenance cost, mechanism, life time of the system. Every day waste produced from kitchen of school canteen; washroom is around 20 liters on average. Waste includes rice, vegetables, dal, bread, pickle, fruit waste, lemon etc. The distance of pipeline is 18 meters from the system to stoves. Beside kitchen Waste, cow manure and human waste has been fed on the system.

The temperature of the surrounding of the plant is noted down at regular interval of the time to note down the maximum and minimum temperature. The gas flowmeter is used to find out the total gas used per day. It is installed outside of the kitchen of the school. The kitchen has been operating four times a day, earlier morning (7:00-7:45 A.M.) to prepare breakfast, at noon (12:30-1:00 P.M.) for lunch, at late noon (3:30-4:00 P.M.) for snacks and for dinner at night (7:00-8:00 P.M.). The reading from gas flowmeter (Zhejing Chint instrument and meter co. ltd) has been noted down daily by the plant caretaker and the cook at 5:00 P.M. daily in a provided log-sheet paper. The data has been taken at atmospheric pressure. The data is taken from the 23/06/2022 to 04/08/2022. The initial and final reading of the gas flowmeter during my study in 499.20 and 727.09 m^3respectively.The pH of the system is regularly measured at fixed intervals, once per week. The pH meter used for testing the output slurry is calibrated every time before the use as it provides accurate and precise data. The meter is calibrated by dipping the bulb of the pH meter in beakers containing buffer solution having pH of 4.0 and 7.0. The test duration is same as the gas flow measurement duration.The sample is prepared in weightage of 30% CM and 70% kitchen Waste. CM was diluted with water. They all are mixed and stirred gently to form a mixture of waste which has been taking at the lab for performing the test of TS, VS & NPK. One liter of feedstock sample along with digested output slurry of one liter has been taken.

The feeding of the samples is CM, kitchen Waste, and human waste. CM is fed thrice a week whereas kitchen Waste is fed twice a day, morning at 9:00 A.M. and evening at 8:00 P.M. Human waste is fed directly through connected pipe.The sample is prepared in weightage of 30% CM and 70% kitchen Waste. CM was diluted with water. They all are mixed and stirred gently to form a mixture of waste which has been taking at the lab for performing the test of TS, VS & NPK. One liter of feedstock sample along with digested output slurry of one liter has been taken.

Calculation of Total Solids, Volatile Solids and NPK (Nitogen, phosphorous, Potassium) The prepared sample is taken NESS lab situated at Thapathali, Kathmandu. In order to calculate TS, initially, required amount of sample was taken and placed on top of a clean, dirt free, dehydrated and pre-weighed watch glass. Again, it was weighed precisely. Then it was dehydrated in burning air oven at about 105°C of temperature for 5 hours. The identical procedure was often repeated until a desired outcome was attained. Also, in order to calculate VS, A clean watch glass is ignited at 550°C for 1 hour inside a furnace. Numerically,

Mass of empty watch glass = W gm

Mass of watch glass + sample added = X gm

Mass of watch glass + sample after drying at 105°C = Y gm

Mass of watch glass + remains after ignition at 550°C = Z gm

$$\text{Total solids (TS)} = \frac{Y-W}{X-W}$$

$$\text{Volatile solids (VS)} = \frac{Y-Z}{Y-W}$$

Calculation of biogas production with reduction of TS and VS
m^3 of biogas/kg of VS = Cumulative gas production/ (Total fed x reduction in VS)

Methods used to test the sample for TS, VS and NPK

S. N	Parameters	Test methods
1.	Total solids (%)	Method 1664, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, Procedure no.11
2.	Volatile solids, (%)	Method 1684, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, procedure no. 11
3.	Total Kjeldahl Nitrogen, (%)	Modified Kzeldahl, FAO, Fertilizer & Plant Nutrition Bulletin No. 19
4.	Phosphorus as P_2Os, (%)	Vanadomolybdophosphoric acid, FAO, Fertilizer & Plant Nutrition Bulletin No. 19
5.	Total Potassium as K_2O, (%	Flame Absorption, AAS, FAO, Fertilizer & Plant Nutrition Bulletin No. 19

Figure 3: Methods to test the sample

4. Results and Discussion

Specification of Plants The TED model has the system volume of 20 m^3, gas tank volume of 8 m^3 and digesters tank of 12 m^3. The height and length of the system is 4.1m and 6.5m and the radius of the hemisphere is the 2.72m. The biogas plant also has a water treatment system known as Anaerobic Baffled Reactor (ABR). The ABR consists of the 9 sections of total length 8.85 m length and each section having cross section area of 0.45 x 0.45m^2 and depth of 2.15m. The last three sections of the ABR consist of graveled type structures up to a height of 1.3m of two different type of gravel. On average daily kitchen waste input was 22 kg, animal manure input 10 kg, Night soil 52 kg.

Also, Modified GGC-2047 model which a fixed dome type digester is size of 20 m^3. The plant is constructed by the Byangnasi Nirman and Suppliers Pvt. Ltd, and installed in the Nepal Sainik War College, Nagarkot. The plant has feeding of near 30 kg of kitchen waste on average and night soil of 40kg per day. The maximum average temperature of the plant was about 27.34°C.

pH variation When the system is at stable condition and running well, then we have only started to perform the testing of pH material. The testing was performed on weekly basis for a month only. pH value of feedstock is found to be about 6-8. Initially, pH has been not low, not up to the optimum value required as feeding has been dominant with kitchen Waste over CM and human waste. Low value of pH for over a long period of time has direct negative effect on biogas production. Earlier CM is used once in week but due to low value, CM proportion has increased to get pH better. After addition of more CM, thrice a week, the pH increases near the neutral about 7.0. As the input of the CM is increased, pH of the input feedstock acts very significant in the biogas creation. When there is better production of the biogas, pH value remains between the value of 7 and 8.

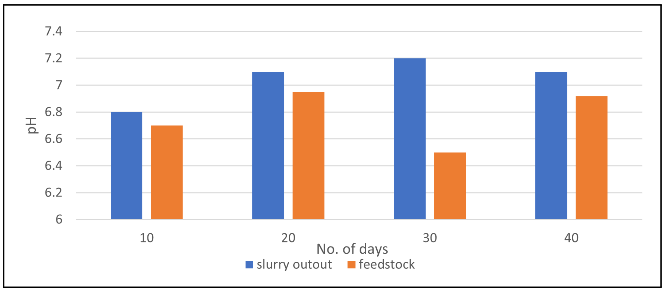

Figure 4: pH output of the system

Biogas Production The data has been taken for 45 days. It has started from 23rd June,2022 to 8th August,2022. The data is more of constant throughout the inspection time. Initially, the value at the gas flowmeter was 499.20m^3 as the biogas plant is running since 15th Feb, 2022 and the last day of meter shows 740.33 m^3. The gas output per day has been 5.425 m^3 on average. The data is taken regularly for 45 days of time interval. The cumulative gas output curve relation is almost linear with time. The cumulative gas output is about 246.13m^3. Production of gas varies from 0.29 m^3 to 8.2 m^3 i.e., 290 liters to 8200 liters per day.

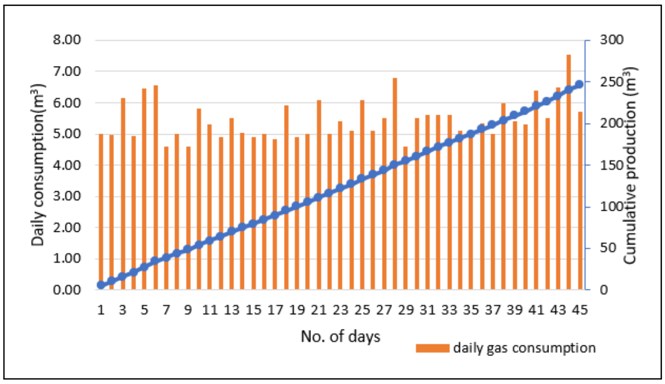

Figure 5: Cumulative Gas Output with daily gas consumption in m^3

Biogas Composition Biogas consists of various other gases along with methane. With the help of Gasboard-3200 plus portable biogas analyzer, percentage of methane content is 46.5%, percentage of CO_2 is 20.62% and the concentration of the H_2S is 9999 ppm which is good range. Concentration of the H_2 and CO was 0 ppm.

Reduction in TS and VS The methane production is nearly 46.50% of the biogas produced so the methane produced during reduction of TS & VS is 0.469 m^3 of CH_4 /kg of TS and 0.102 m^3 of CH_4/kg of VS respectively. The biogas produced during the TS and VS reduction is 1.01 m^3 of biogas/ kg of TS and 0.22 m^3 of biogas/ kg of VS respectively. the output of the organic mixture of kitchen Waste and black water gives a maximum of 0.520 m^3 of CH_4/ kg of VS also the output of the FVW & FW is 0.30 & 0.56 m^3 of CH_4/ kg of VS respectively. the potential of methane in the FW falls in the range of 0.3-1.1 m^3 of biogas/kg of VS, which is generally higher than other AD substrates like CM, HW(Human waste) and lignocellulosic biomass[4].

Reduction in NPK The output from the biogas system is methane as biogas and fertilizer, both are useful in daily life and also good in context of the environment as the plant helps to minimize the odor and bad smell of the degraded material and also has very low toxicity. The fertilizers produced in this way has high value of nutrients and which helps in vegetation and plantation. The digested slurry has also low quantity of metals and compared to the synthetic and industrial fertilizers. Digested slurry when mixed with synthetic fertilizers, it helps to increase the nutrient needed for the plants to grow. During AD process, there is formation of nitrogen, phosphorus and potassium. The amount of the nitrogen gets converted in the ammonium, which is readily available for the plant growth. Some phosphorus also gets converted to t phosphorus which are in a soluble form. The digested slurry has N, K_2O_5 and P_2O_5 are 3.1, 1.7, and 3.2% respectively.

CO_2 Reduction in emission from the biogas plant The reduction of CO_2 annually from the installation of the biogas plant is shown in the table 4.2. As the plant is of institutional type, so there are some annual public holidays is deducted from the total operating of the plant. So, as the school is of hostel type only long holidays are counted as holidays and is deducted. So. Nearly 50 public holidays are considered for reduction.[14]

Total waste fed per day	84	kg
Conversion factor	2.20	kg of CO_2 equivalent
Total CO_2 equivalent	0.0381	Tonnes of CO_2 equivalent
Total CO_2 equivalent/ per annum	12.027	Tonnes of CO_2 equivalent

Figure 6: Reduction in CO_2 emission from the biogas plant

Biogas output comparision In the modified GGC-2047 model, the gas output is about 4.1m^3 per day. The maximum average temperature of the plant was about 27.34°C. While in case of the TED model the average feeding of feedstock is nearly 84 kg and gas output per day is 5.425 m^3 per day and at maximum average temperature is 27.71°C. Feeding includes the kitchen Waste, HW, and CM.

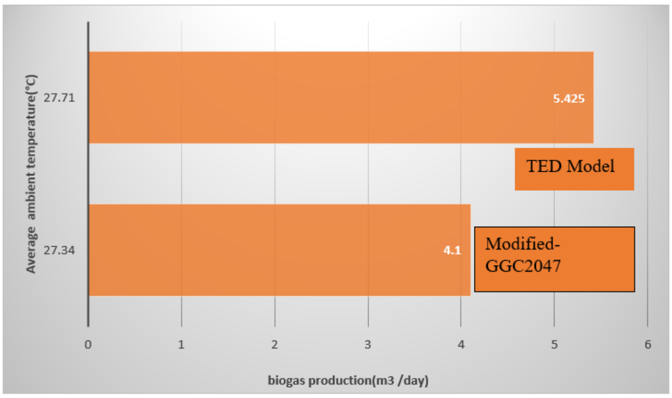

Figure 7: Comparison of biogas production from TED model and modified GGC-2047 model

Financial Analysis Financial analysis of both the model is shown in figure

	Modified GGC-2047 (20 m3)	TED Model (20 m3)
Initial cost (Rs.)	790,825	1,893,927
Subsidy (Rs.)	240,000	0
Annual O & M cost (Rs.)	12,000	12,000
Life	25 years	25 years
Annual Biogas production (m3)	1,476	1,953
Annual revenue from Gas production (baseline on LPG saving(Rs.)	82,697	109,995
Annual revenue from waste management(Rs.)	15,000	25,000
Annual net cash flow (Rs.)	85,697	122,995
Simple Payback period (years)	6.4	15.4

Figure 8: Simple Payback period calculation for different biogas plant

5. Conclusions

The percentage of methane content is 46.5%, percentage of CO_2 is 20.62% and the concentration of the H_2S is 9999 ppm which is good range. Concentration of the H_2 and CO was 0 ppm. TS of the inlet feedstock and outlet slurry were 14.58% and 8.13%. It is found that there is good reduction rate in TS with 44.24 %. Also, the VS inlet feedstock and outlet slurry were 78.59 % and 48.95%. The degradation rate in VS was 37.71 %. From the plant it is also found out that 1.01 m^3 of biogas/ kg of TS and 0.22 m^3 of biogas/ kg of VS respectively was produced. And 0.469 m^3 of CH_4 /kg of TS and 0.102 m^3 of CH_4/kg of VS respectively methane was produced. The NPK of inlet feedstock were 0.37%, 1.54%, 0.25% and outlet slurry were 0.17%, 0.68%, 0.03% respectively.The average gas production per day was 5.425 m^3 i.e., 5425 liters. The cumulative gas consumption/production was 246.13 m^3.So, per hour biogas production from TED model was 226.04 liter at maximum average temperature of 27.11°C whereas from modified GGC-2047 plant was 4.1m^3 per day at maximum average temperature of 27.34°C. Financial analysis has shown that due to large investment of the plant in compare with standard model the payback period is high and NPV is also in negative even if it gets subsidy only a little improvement is found the payback period and NPV.

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